Novel Methods of p-type Activation in GaN:Mg

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We developed two novel methods for the activation of GaN:Mg. High hole concentrations exceeding 10^{18}cm^{-3} were obtained in both long-time low-temperature annealing and radio frequency (RF) activation. Over 80 hours of 385°C in air was required in order to achieve the maximum hole concentration. On the other hand, high hole concentrations were realized in under a minute using RF activation.

The activation of p-type dopants in III-V nitrides is one of the most important issues in the production of GaN based devices. Mg is commonly used as an acceptor dopant for III-V nitrides and it is recognized that Mg-H complexes are responsible for high resistivities in as-grown GaN:Mg. It is suggested that Mg activation occurs as a result of the thermal dissociation of Mg-H complexes. There are several reports concerning the method of activating GaN:Mg.[1-4] However, to our best knowledge, there have as yet been no studies into the dependency of annealing time at temperatures below 500°C.

In this study we test two new methods for the activation of p-type GaN:Mg; a long-time annealing method and a RF activation method. Schematic diagrams of the two methods are provided in Fig.1. Test samples included a 1µm-thick GaN:Mg layer on a 2µm-thick undoped GaN layer over a buffer layer grown on a c-plane (0001) sapphire substrate. For the long-time annealing method, the samples placed on a SUS plate and annealed in air at temperatures of 385 °C, 415 °C, and 485 °C. For the RF activation method, the samples were placed between RF electrodes to which strong electric fields were applied. Background air pressure was maintained below 10^{-5} Torr in order to prevent the generation of plasma. A radio frequency of 13.56MHz was used in this experiment. Hall and photoluminescence (PL) measurements were performed in order to evaluate the electrical and optical properties of the layers.

The relationship between annealing time and p-type hole concentration for each temperature is shown in Fig. 2. Annealing was performed as shown in Fig.1(a). As the hole concentration increased in proportion to the square root of annealing time, Mg activation was thought to basically be related to hydrogen diffusion. The activation energy for this process was estimated to be ~1.7eV from Arrhenius plots. For the anealment process at 385°C, the hole concentration reached approximately $1x10^{18}$ cm^{-3} after 80 hours. To the best of our knowledge this is the first time that high hole concentration have been achieved in an activation process below 400°C.

The relationship between RF input time and hole concentration is shown in Fig.3. The maximum strength of the RF electric field was ~21kV/cm. The heating temperature was 300°C. Hole concentrations increased with RF application time. In this case, we obtained high hole concentrations in under 1 minute. The activation time is reduced dramatically using this method, however further investigation is necessary to better understand the activation mechanism of this method.

The relationship between the hole concentration and PL intensity is shown in Fig.4. The PL intensities of thermally activated samples, annealed between 475°C and 800°C in an N_2 atmosphere, are plotted for comparison. The power density of the PL was 700mW/cm^2. The maximum PL peak intensities near 450nm were measured. The PL intensity decreased as the hole concentration increased in all activation methods. There is no specific difference in the PL intensity for each method. This indicates that our new activation methods should be no less effective than conventional method.[2)]

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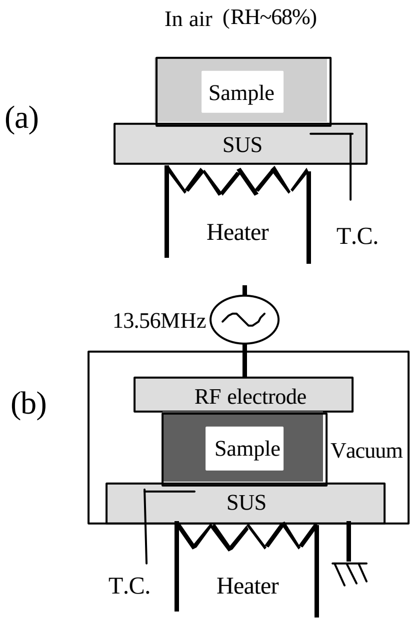

Fig. 1. Schematic diagrams of systems (a) low-temperature annealing in air (b) RF activation.

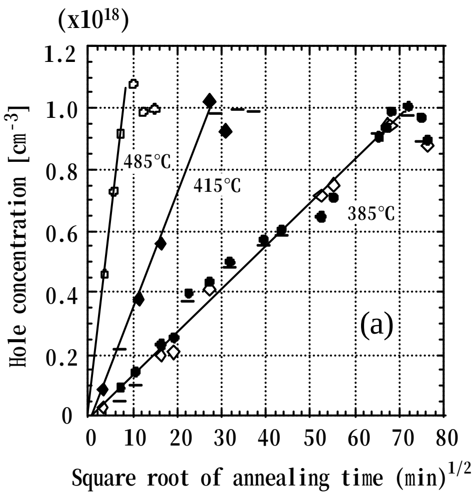

Fig. 2. Relationship between annealing time and hole concentration for annealed samples.

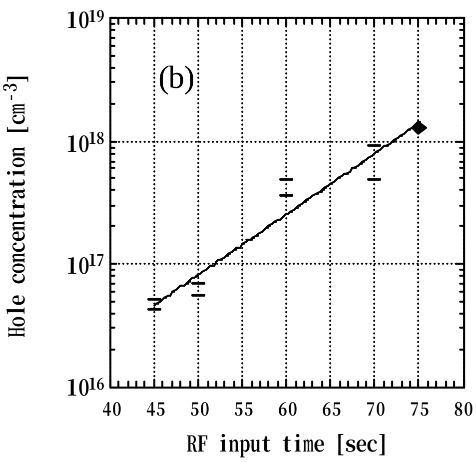

Fig. 3. Relationship between RF application time and hole concentration for RF-activated samples.

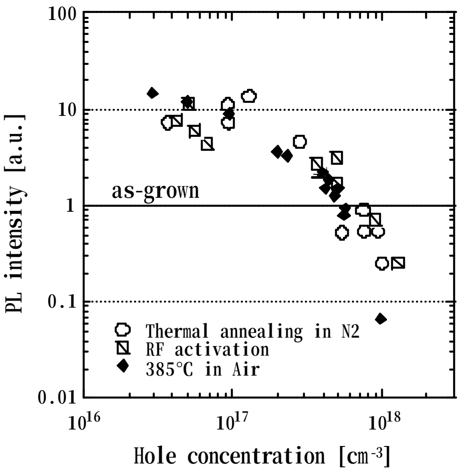

Fig. 4. Relationship between hole concentration and PL intensity normalized to as-grown GaN:Mg.